Measurement of Top-Yukawa coupling at the early stage ILC

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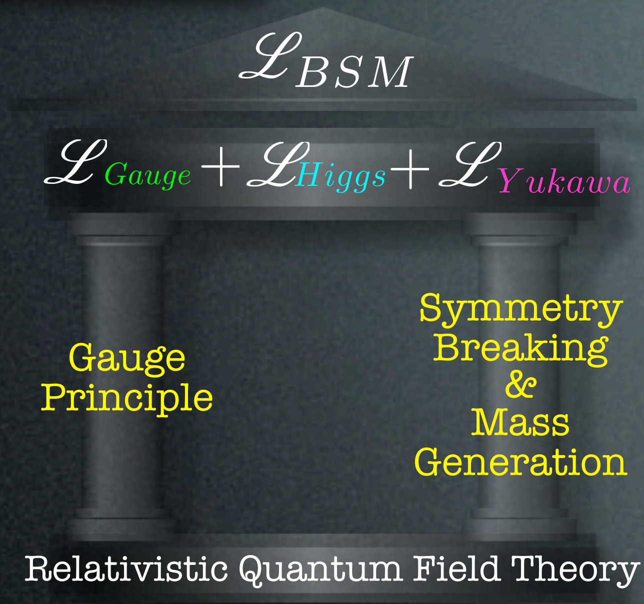
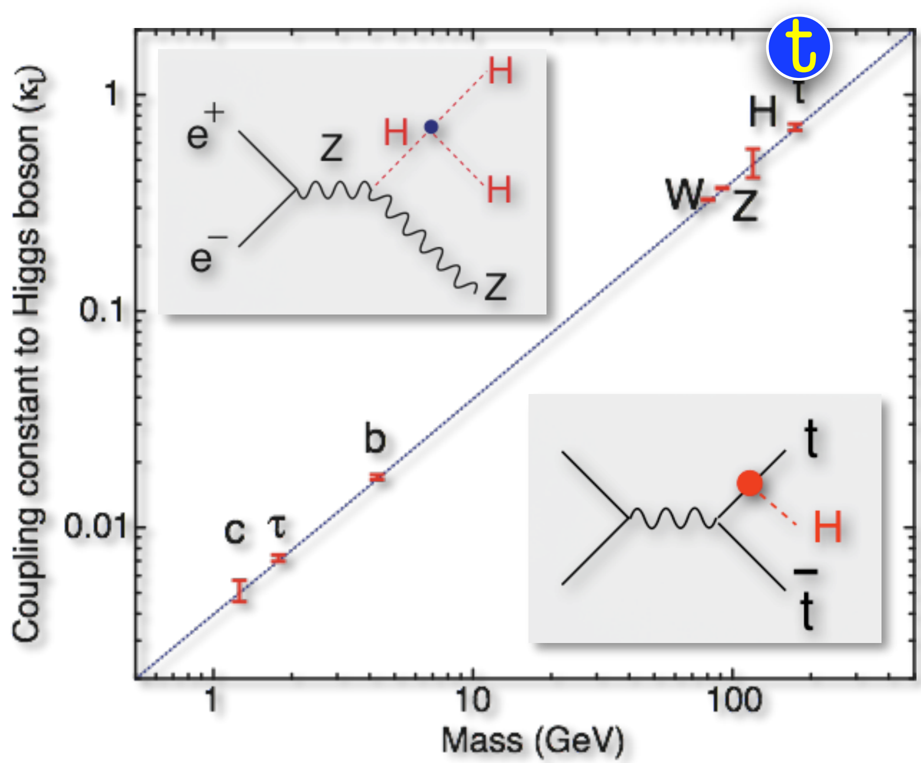


Relation between mass and coupling constant with Higgs



Two pillars of SM

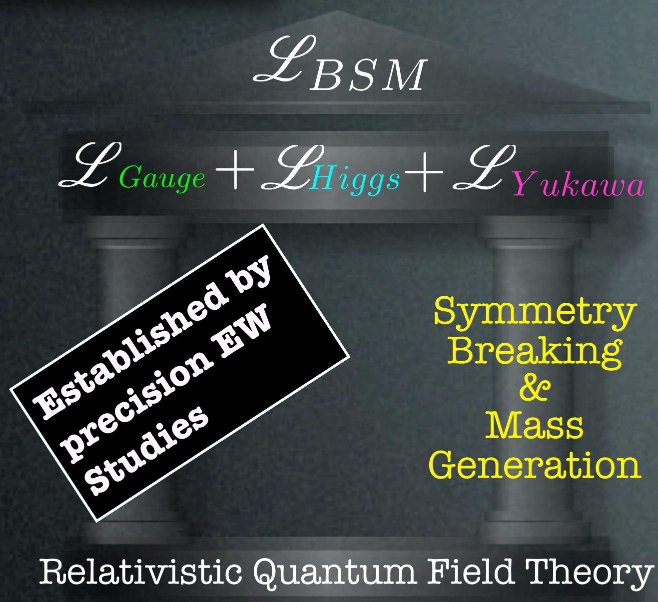
Standard model consists of two pillars:

- One pillar, gauge symmetry, has been established by precision EW studies.
- Another one, higgs mechanism, is still untested.

A critical mission for the ILC is the Higgs coupling measurement !

Higgs self coupling will be tested at ～**500** GeV where e+e- -> ZHH cross section attains its maximum.

Our motivation is to confirm the untested pillar by measuring Top-Yukawa coupling at 500 GeV (1st stage of ILC) concurrently to measuring Higgs self coupling.



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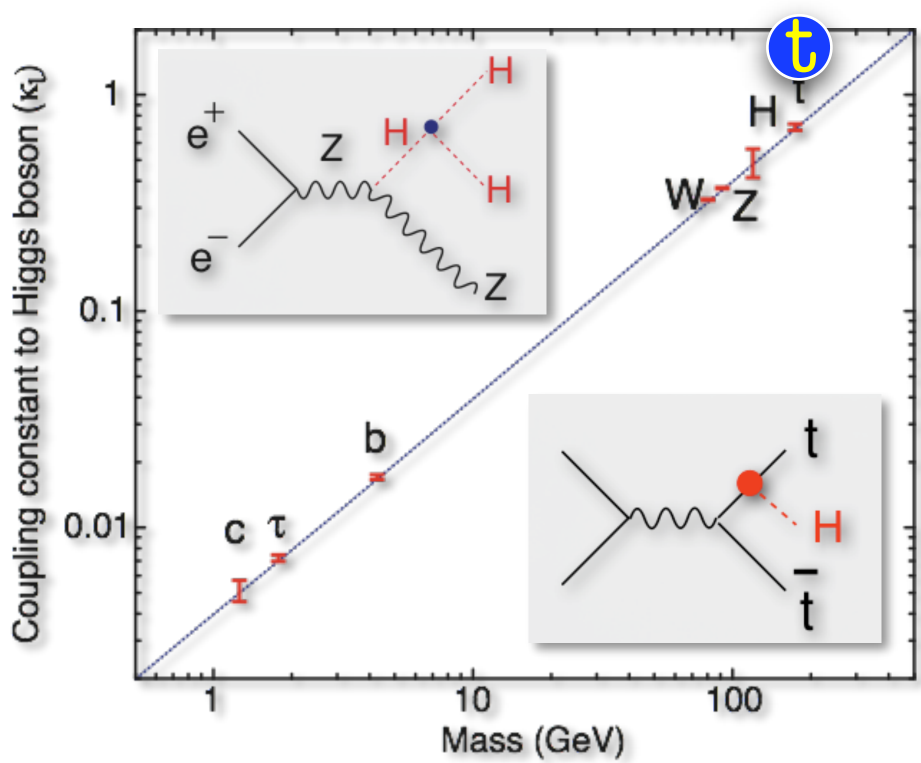

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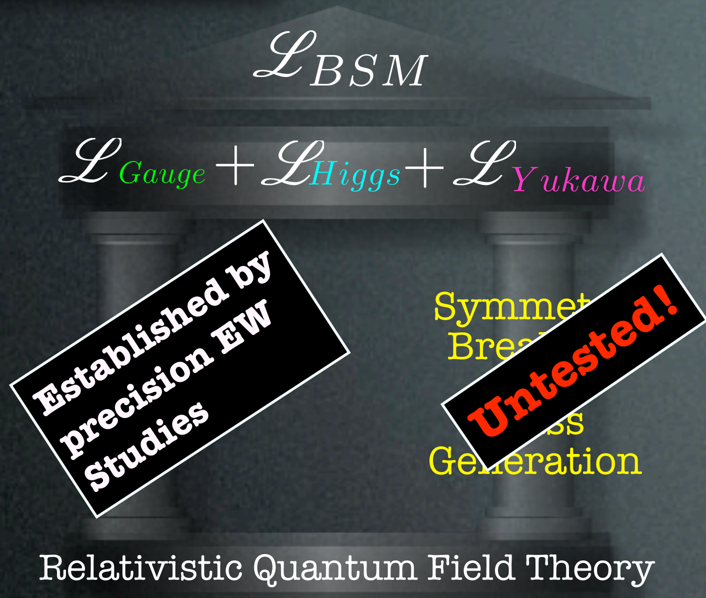

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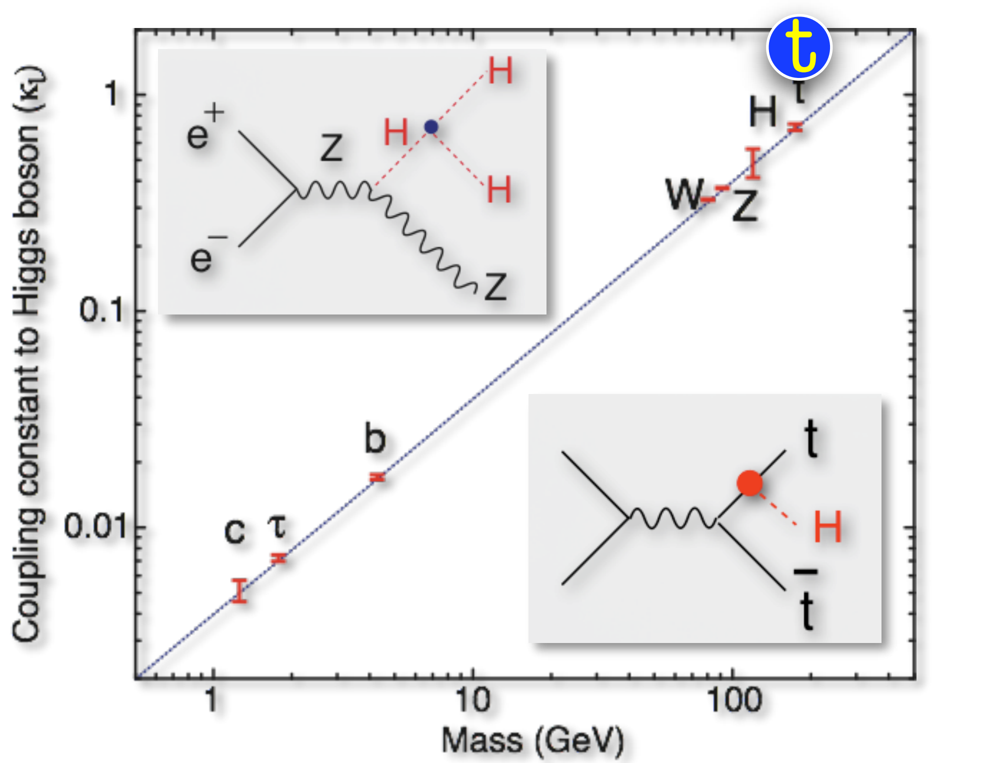

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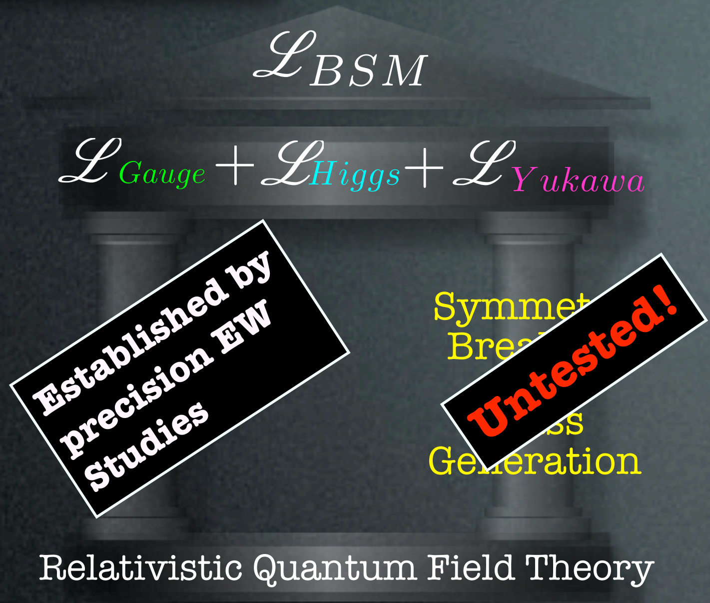

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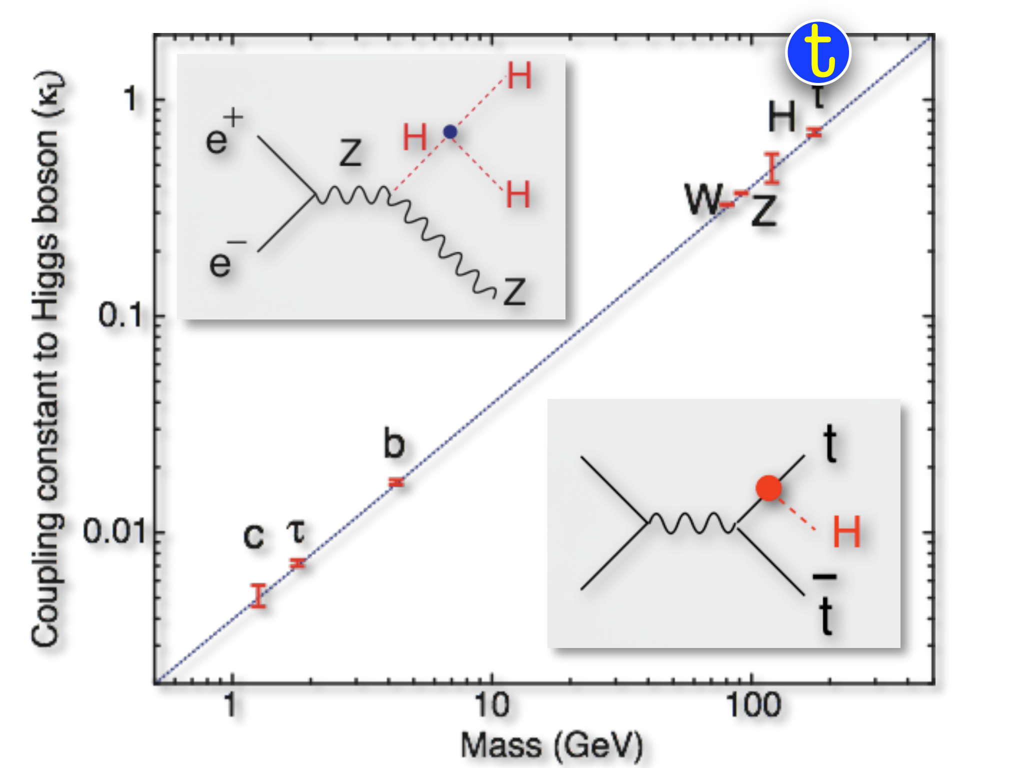

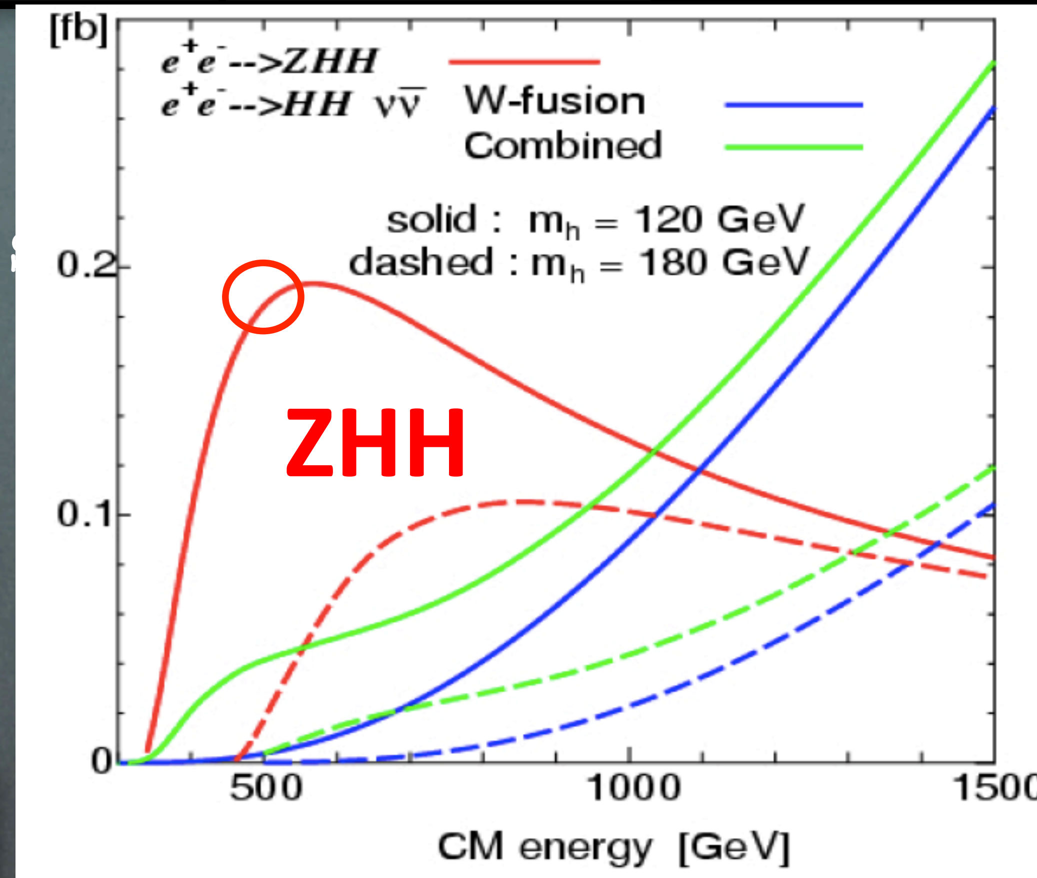

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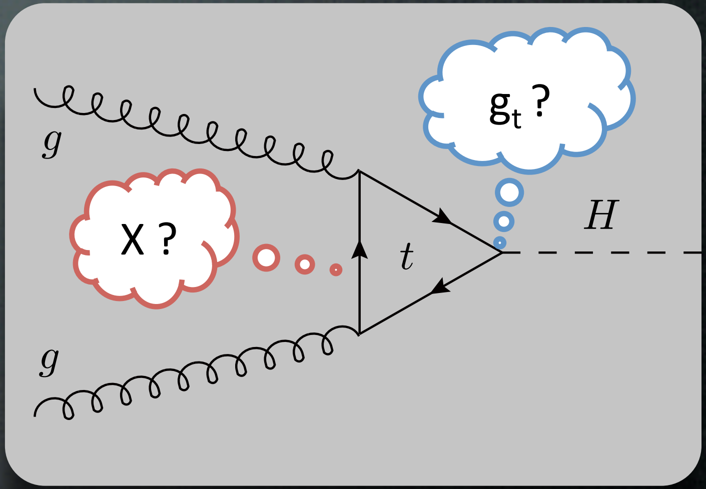
Top-Yukawa coupling < indirect measurement / direct measurement

- indirect measurement

The Higgs sector offers a broad range of possibilities for new physics ...

There is a possibility of a new particle X being in the loop.

difficult to distinguish X loop and top loop!

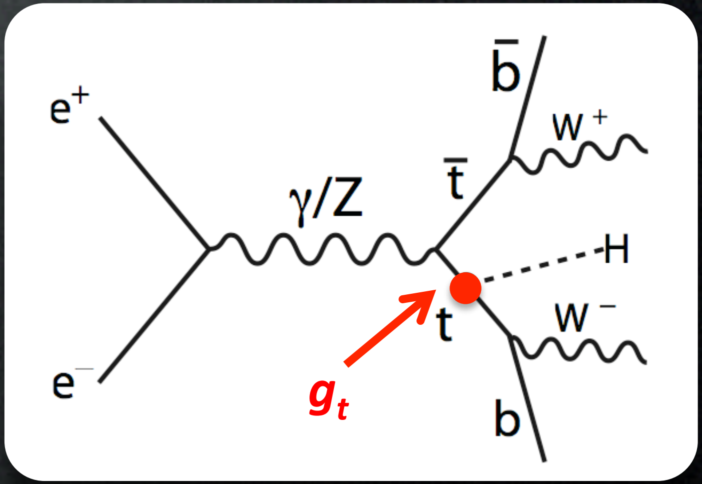


gg -> ttH @ LHC

- direct measurement

promising at ILC !!

main decay mode (H -> bb 68%) can be used



e+e- -> ttH @ ILC

Measurement of top-Yukawa coupling at 500 GeV

Past work estimated the measurement accuracy around E_{cm} = 700 - 800 GeV where the cross section reaches maximum.

500 GeV is nearly threshold of ttH.

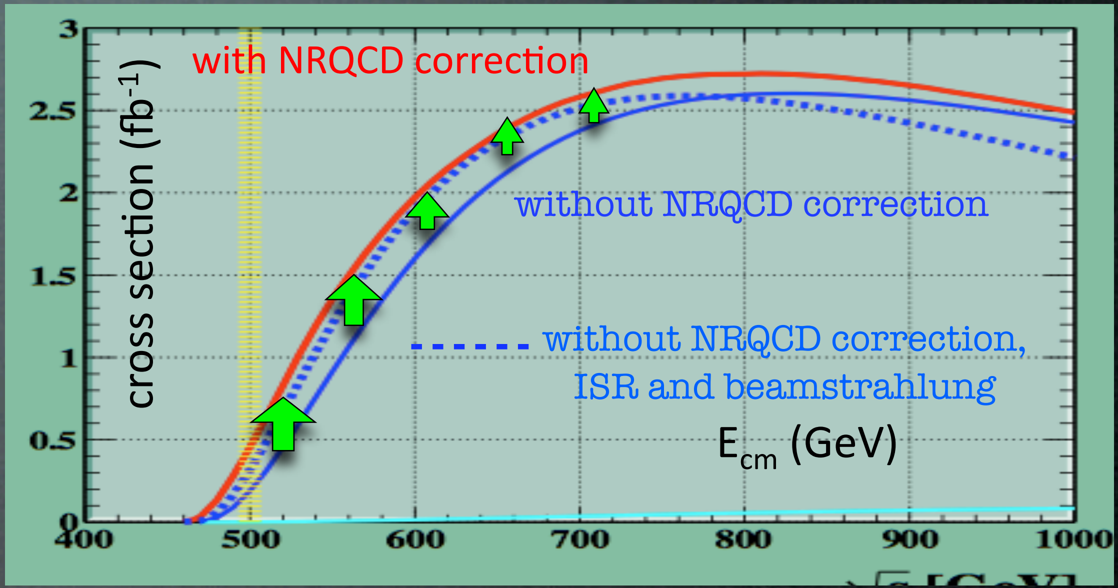
Cross section is smaller than 1 fb!

But ...

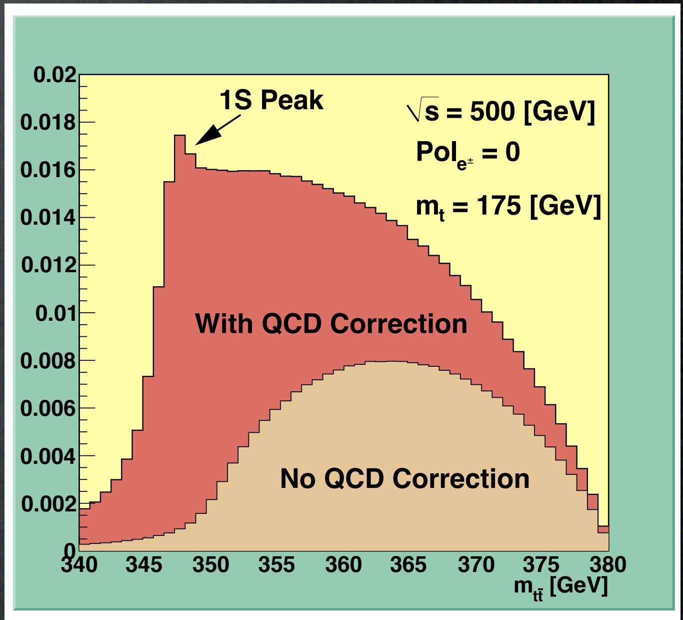
tt threshold correction enhances ttH production (and also ttZ)

This makes it possible to perform the direct g_t measurement at 500 GeV

Cross section of ttH enhancement



Invariant mass dist. for tt sysytem



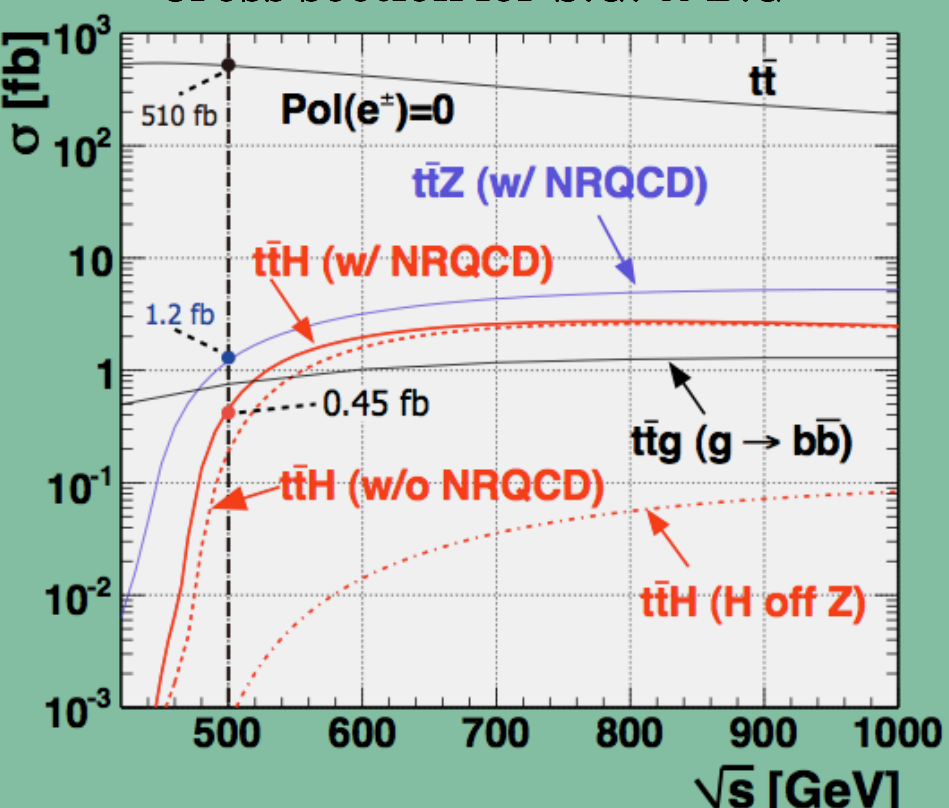
Feature of signal process (e+e- -> ttH)

event signature in our study

ttH ->bWbWbb (H -> bb : 68%)
8jet, 1-lepton + 6jet, and 2 lepton + 4-jet

At E_{cm} = 500 GeV, ttH production is dominated by s-channel γ / Z exchange.

Cross section for S.G. & B.G



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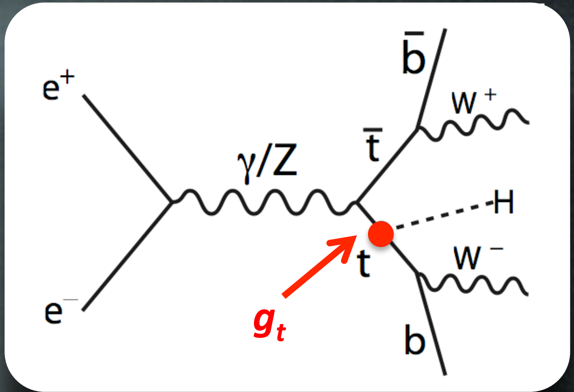
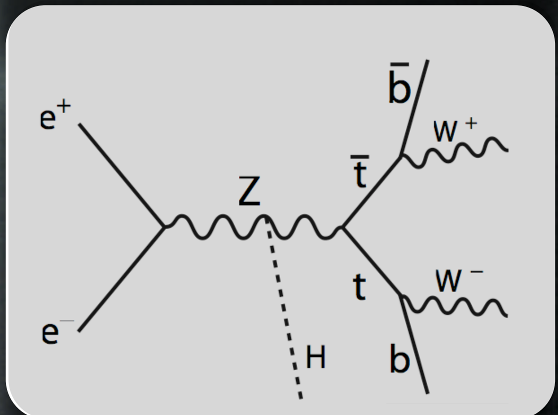


contains g_t



does NOT contains g_t

There is contribution to ttH from Higgs-strahlung. This diagram doesn't contain top-Yukawa coupling. But its contribution is negligible because of small cross section.

The cross section for ttH , tt, ttZ and ttg*(g->bb) are shown in left plot, which includes NRQCD correction to ttH and ttZ.

$\sigma_{ttH} = 0.45$ fb without beam pol.

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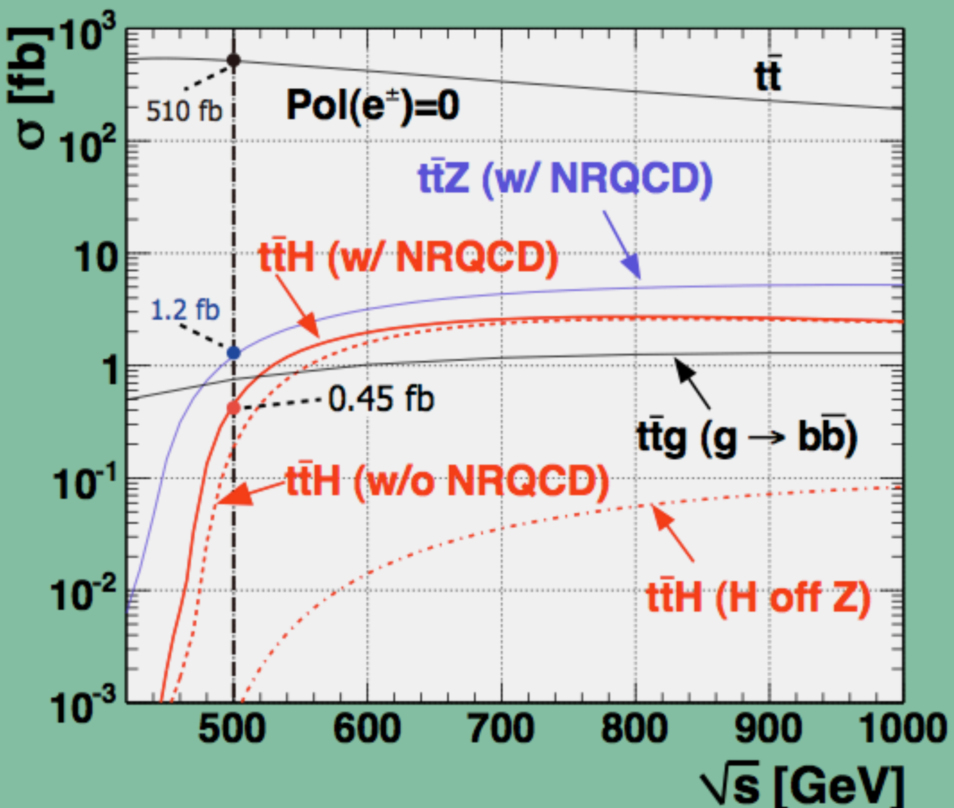
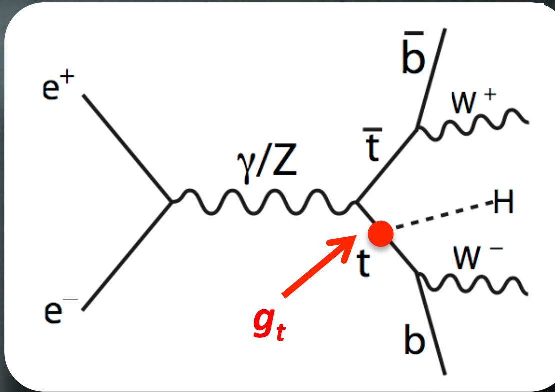


e+e- -> ttH



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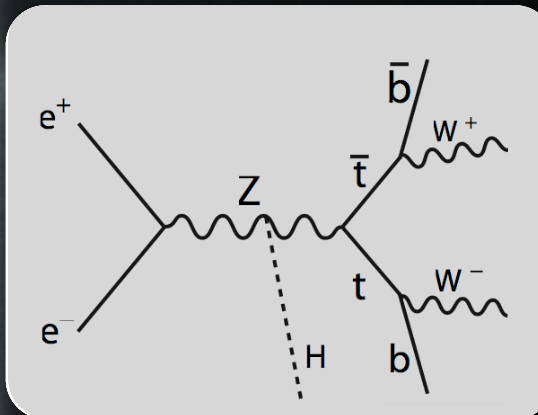

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Backgrounds

Main backgrounds

ttZ followed by Z -> bb (15%) same final state (t t Z -> bW bW bb)

→ irreducible background

tt threshold correction enhances σ_{ttz} from 0.7fb to 1.3fb

ttg* followed by g* -> bb same final state (t t g* -> bW bW bb)

→ irreducible background

tt
- huge cross section (500fb)
- hard gluon emission from bottom quarks mimic signal
- even a tiny fraction of mis-reconstruction or b-tagging failure leads to significant background contamination.

The other possible backgrounds ?

W*W*/Z*Z -> ttbb small contribution (< 0.01fb)

qq (5 flavors), WW, ZZ, ZH have different signature from ttH signal.

- can be separated with 4×b tagging, event shape cut and mass cut

We generated signal(ttH) and main backgrounds (ttZ, ttg*, tt).

Basic idea to reduce backgrounds

backgrounds	tt	ttZ	ttg*
event shape compared to ttH	Effective ! different	same	same
maximum number of b-jets	2	4	4
Higgs candidate(Z, g*) mass compared to H	none	Effective ! different	Effective ! different

Analysis Framework

- Event generator : physsim
  - full helicity amplitude calculation by HELAS
  - MC phase space integration by BASES/SPRING

  ISR & beamstrahlung are included

  NRQCD correction for ttH and ttZ is included

  Dedicated ttg generator with correct color strings

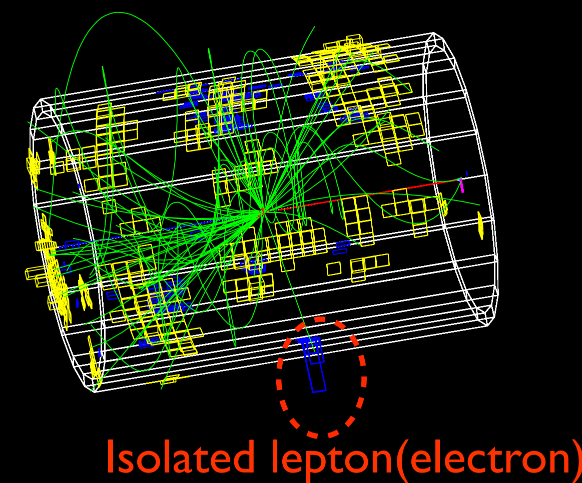
- Parton shower & hadronization: pythia

- Fast detector simulation: JSF

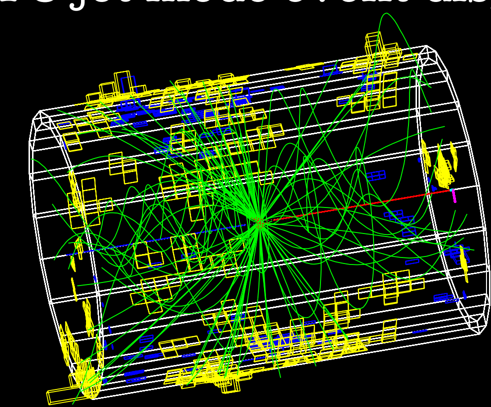
Detector parameters

Detector	Performance	Coverage
Vertex detector	$\sigma_b = 7.0 \oplus (20.0/p)/\sin^{3/2}\theta \mu m$	$\lvert\cos\theta\rvert \leq 0.90$
Central drift chamber	$\sigma_{P_T}/P_T = 1.1 \times 10^{-4} p_T \oplus 0.1\%$	$\lvert\cos\theta\rvert \leq 0.95$
EM calorimeter	$\sigma_E/E = 15\%/\sqrt{E} \oplus 1\%$	$\lvert\cos\theta\rvert \leq 0.90$
Hadron calorimeter	$\sigma_E/E = 40\%/\sqrt{E} \oplus 2\%$	$\lvert\cos\theta\rvert \leq 0.90$

ttH L+6-jet mode event display



ttH 8-jet mode event display



Charged particle tracks

Signals on H-Cal.

Signals on E-Cal.

Cut values

the following values were chosen to yield optimized value of measurement significance.

6-Jet + lepton	8-Jet
# of isolated lepton = 1	# of isolated lepton = 0
$Y_{5\to4} = 0.005$	$Y_{8\to7} = 0.00082$
thrust > 0.85	thrust > 0.8
b-tagging (at least 4 b-jet)	b-tagging (at least 4 b-jet)
140 GeV < top mass < 205 GeV	136 GeV < top mass < 205 GeV
90 GeV < higgs mass < 150 GeV	85 GeV < higgs mass < 150 GeV

Cut flow (**6Jet + lepton**, lumi. = 1 ab^{-1}, unpolarized beams)

Cut	ttH(6J+L)	ttH (8J, 4J+2L)	tt	ttZ	ttg* (g* -> bb)	significance
no cut	167	212	514076	1340	697	0.23
Single isolated lepton	106.1	28.6	180112	441	242	0.25
thrust < 0.85	104	27.2	147518	423	225	0.27
$Y_{5\to4} > 0.005$	86.1	17.4	10407	264	84.8	0.82
4×b-tagging	33.9	2.9	137	34.2	28.3	2.21
mass cut	28.5	1.0	27.4	23.6	11.3	2.97

H -> bb (68%) Z->bb (15%)

Cut flow (8Jet, lumi. = 1 ab^{-1}, unpolarized beams)

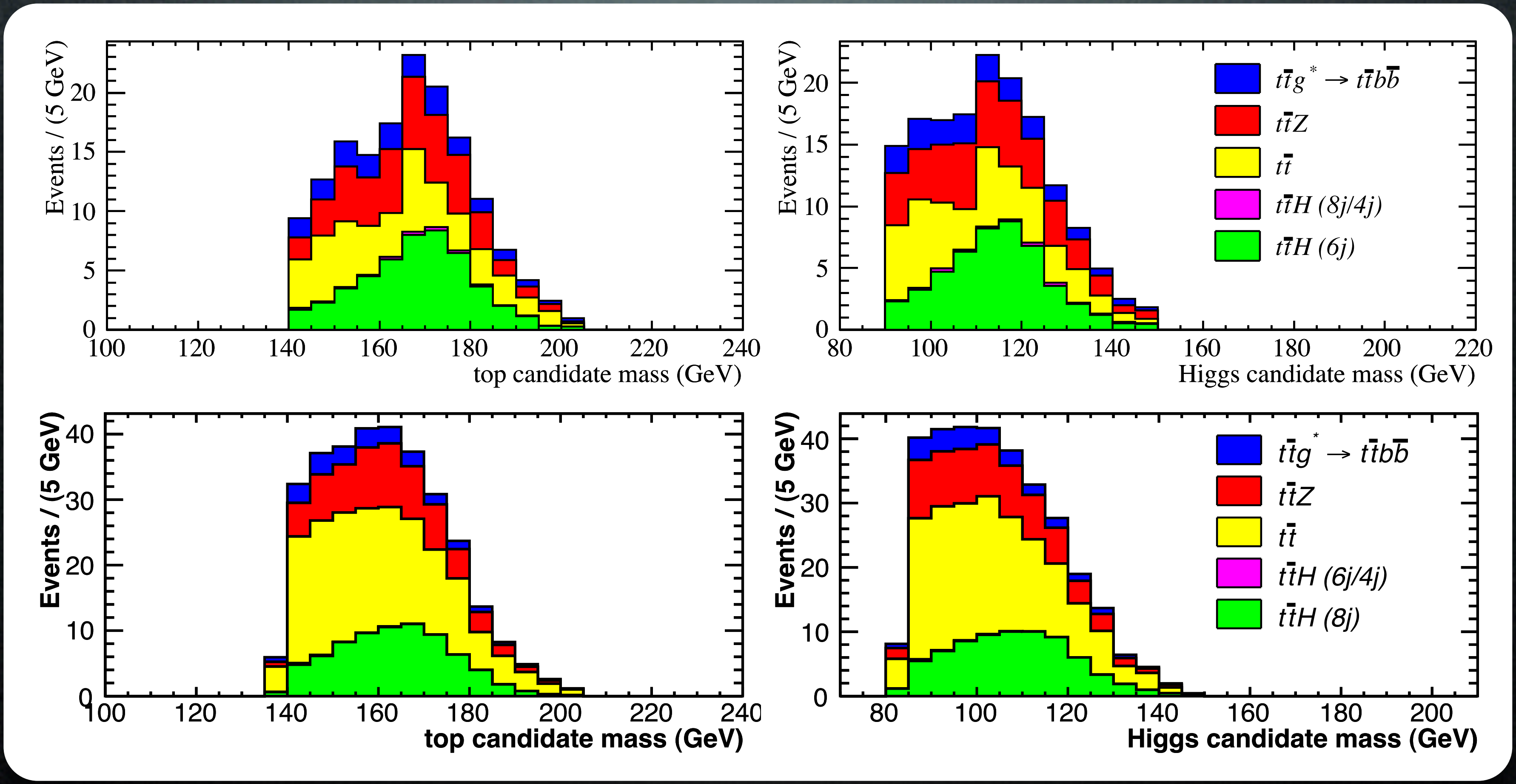
Cut	ttH(8J)	ttH (6J+L, 4J+2L)	tt	ttZ	ttg* (g^* -> bb)	significance
no cut	172	207	514076	1340	697	0.24
Isolated lepton veto	158	54	306582	752	418	0.28
thrust < 0.8	153	49.4	240148	716	377	0.31
$Y_{8\to7}$ > 0.00082	104	13.5	9651	296	79.1	1.03
4×b-tagging	61.3	7.0	357	63.4	46.2	2.65
mass cut	43.8	0.4	93.4	34.5	13.8	3.21

H -> bb (68%) Z->bb (15%)

Mass plot

6-jet + lepton

8-jet



Top Mass

Higgs Mass

Beam polarization $(P_{e-}, P_{e+}) = (-0.8, +0.3)$

Integrated luminosity 1ab^{-1}

Result summary

$1\,ab^{-1}$

Beam pol. (e- , e+)	6Jet+lepton		8Jet	
	S / N	significance	S / N	significance
(0 , 0)	28.5 / 63.3	2.97	43.8 / 142.1	3.21
(-0.8 , +0.3)	48.2 / 107.3	3.87	73.6 / 244.4	4.13

Combined results

$1\,ab^{-1}$

Beam pol. (e- , e+)	Combined significance	Combined $\Delta g_t/g_t$
(0, 0)	4.37	11.4%
(-0.8, +0.3)	5.66	8.8%

(stat. error only)

Summary & Plan

We assumed early stage ILC

- E_{cm} = 500 GeV
- luminosity 1 ab^{-1}
- polarized beams (-0.8, +0.3)

Fast simulation studies suggests
～**10%** accuracy on top-Yukawa coupling is achievable.

We will move on to full simulation studies.

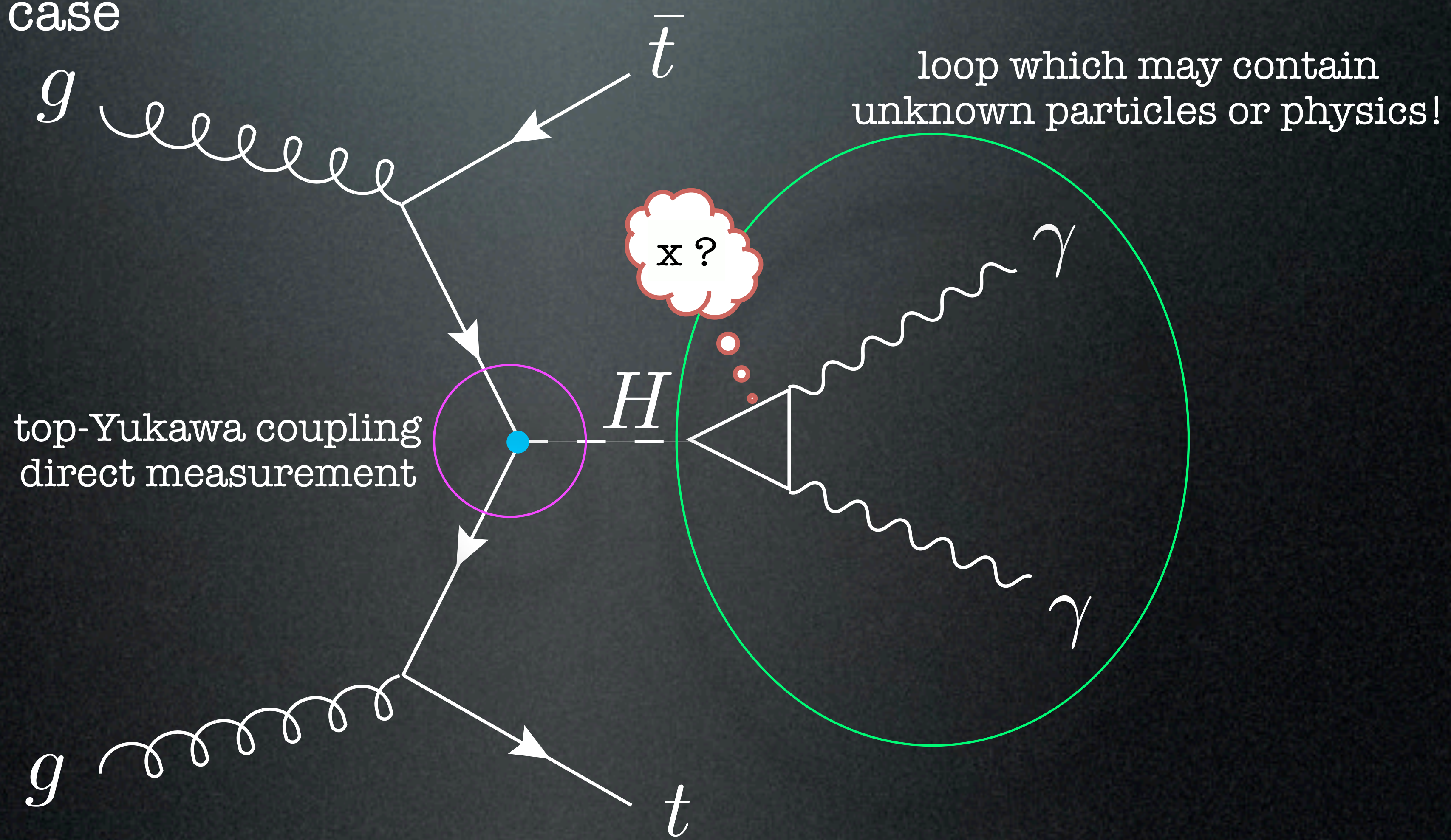
Backup

Direct measurement at LHC

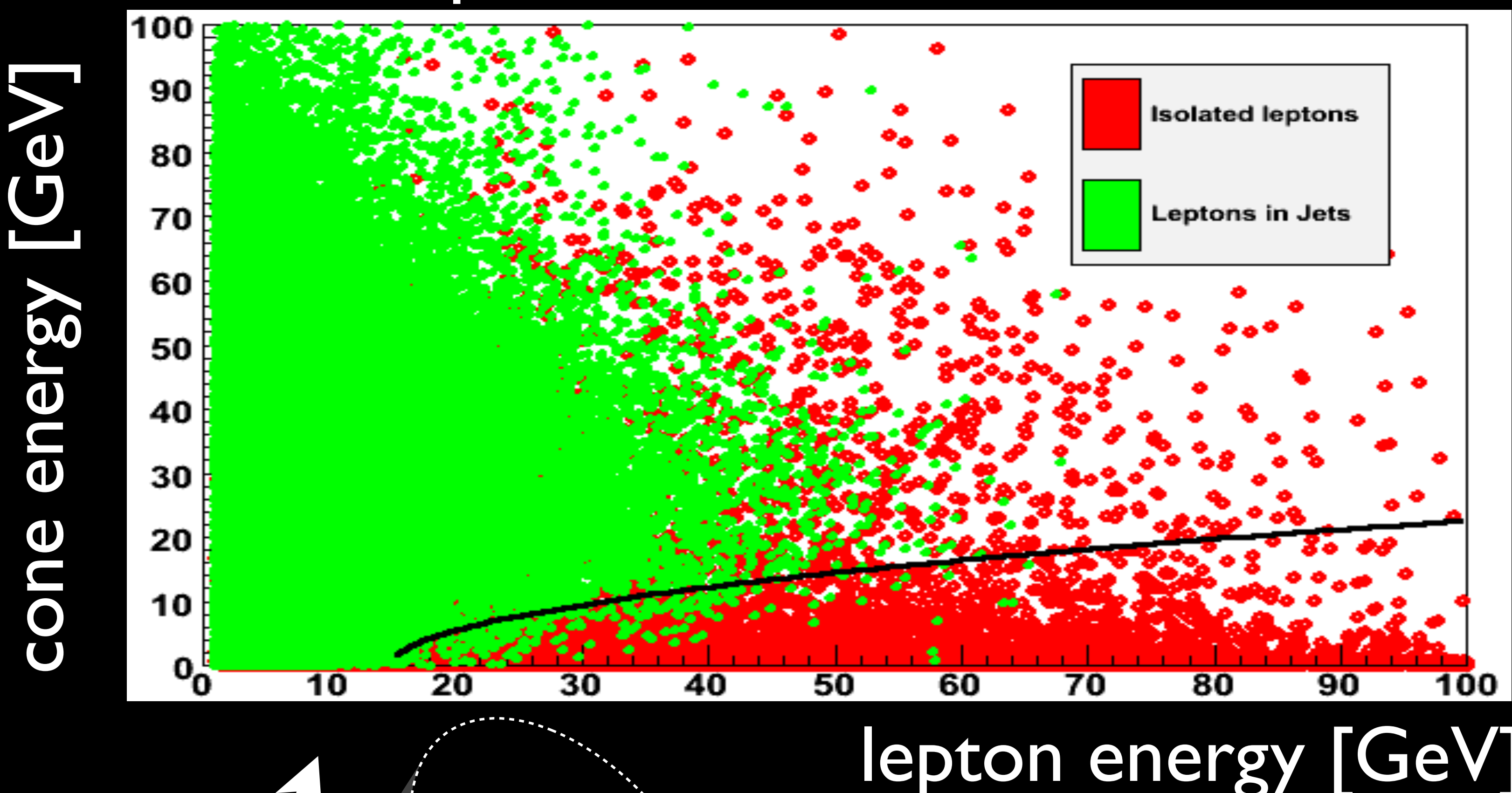
may be possible at LHC using H -> γγ , ττ
but in this case **needs accurate BR(H->γγ, ττ) information**

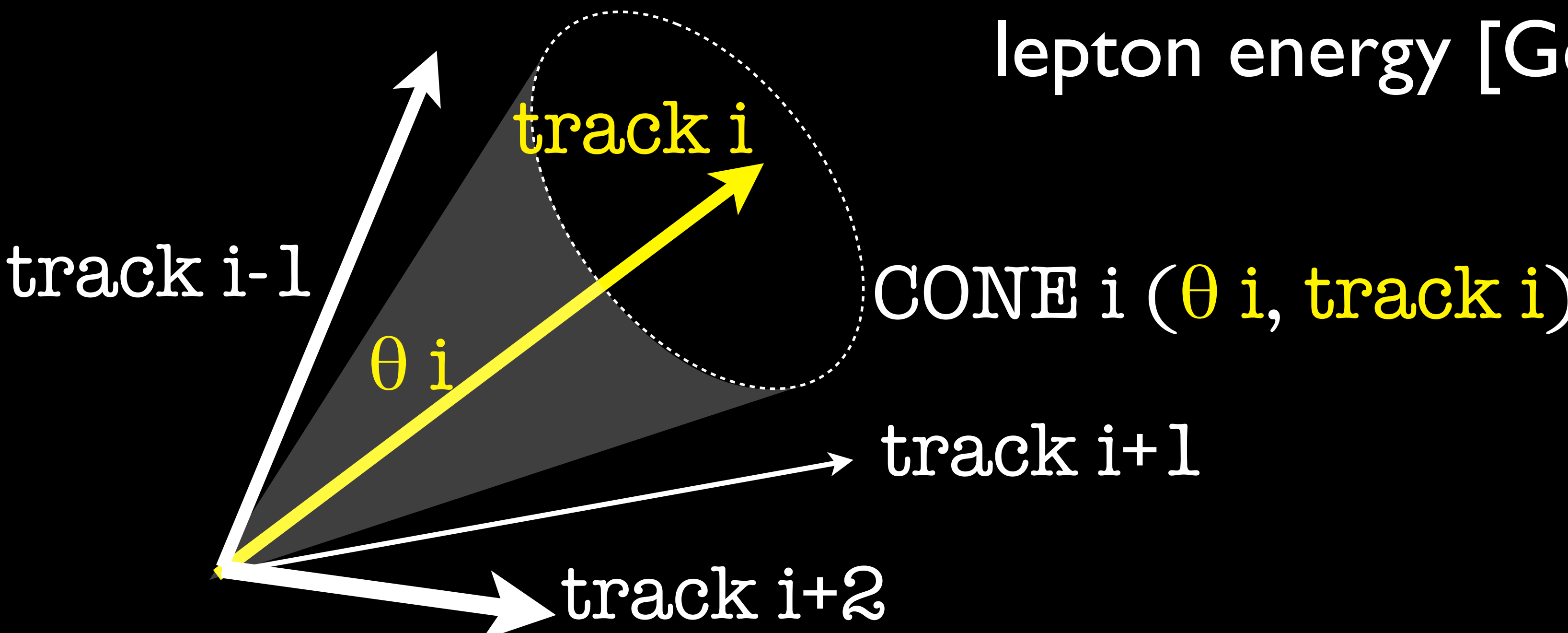
Or need to assume certain model .

H -> γγ case



Isolated lepton



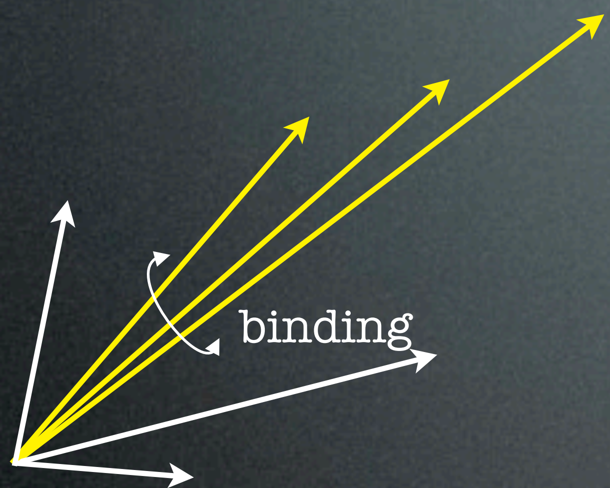


Jet Clustering

using Forced n-jet clustering

Forced n-jet clustering

1. Putting together tracks around a seed track until y reaches a certain value (Ycut).



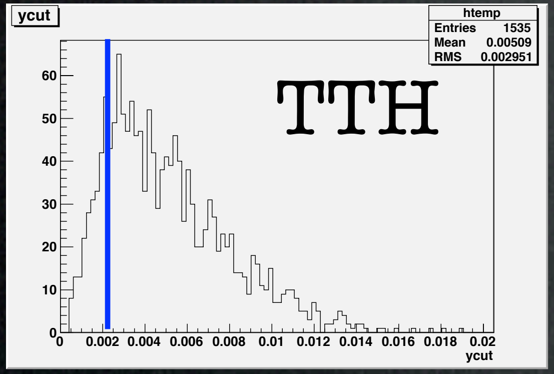
while ...

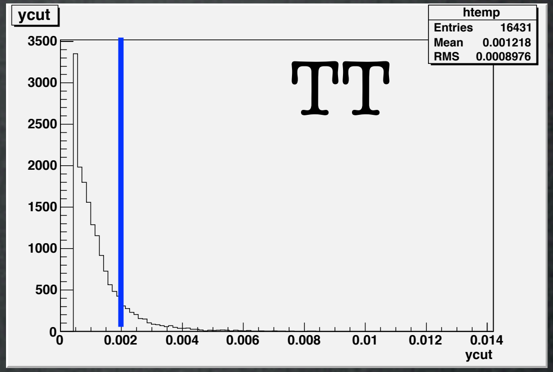
$$Y_{ij} = \frac{\min\{E_i^2, E_j^2\}(1-\cos\theta_{ij})}{E_{cm}^2}$$

(Durham jet clustering)

2. Forced n-jet clustering always makes n jets by adjusting Y_{CUT} automatically for every event.

If we apply Forced 6-Jet Clustering for 4-Jet event, Ycut will be small.





b-tag

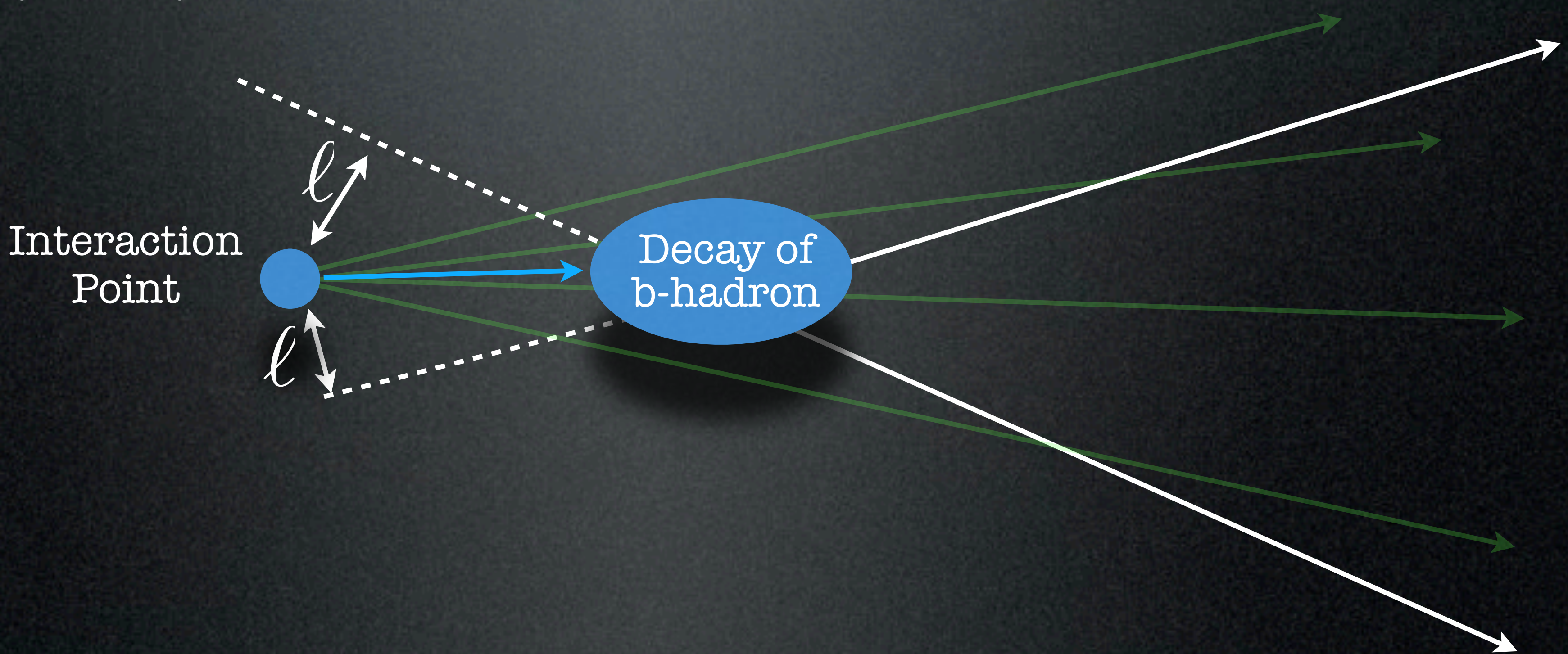
n-sig method

n-sig method

Given the distance between a tracks and IP, ℓ
and the measurement error, σ_ℓ

define the track as “off vertex track” if $\dfrac{\ell}{\sigma_\ell}$ is over a certain value

define the jet as b-jet if the number of “off vertex tracks” in a Jet is over a certain value.



Definition of polarization

$$P_-^e = -\frac{N_-^e - N_+^e}{N_+^e + N_-^e}$$

$$P_+^p = \frac{N_+^p - N_-^p}{N_+^p + N_-^p}$$

N_-^e : # of left handed electrons

N_+^p : # of right handed positrons

g_{tth} measurement accuracy

$$\frac{\Delta g_{tth}^2}{g_{tth}^2} = \frac{\Delta \sigma_{tth}}{\sigma_{tth}} = \frac{\Delta (N_{obs}/(\eta_{all} \cdot L))}{N_{tth}/(\eta_{all} \cdot L)} = \frac{\sqrt{(\sigma_{tth} \cdot \eta_{tth} + \sigma_{BG} \cdot \eta_{BG}) \cdot L}}{\sigma_{tth} \cdot \eta_{tth} \cdot L}$$

χ^2 definition

$$\chi^2 = \frac{(m2j - M_H)^2}{\sigma_H^2} + \frac{(m2j - M_{W_1})^2}{\sigma_{W_1}^2} + \frac{(m3j - M_{t_1})^2}{\sigma_{t_1}^2}$$

$$+ \frac{(m2j - M_{W_2})^2}{\sigma_{W_2}^2} + \frac{(m3j - M_{t_2})^2}{\sigma_{t_2}^2}$$

1 Lepton + 6Jet mode analysis

8Jet mode analysis

ttH analysis

6 jet + 1 lepton mode

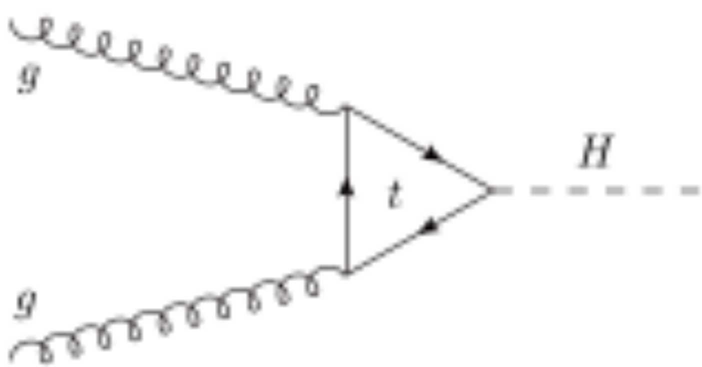
- Find isolated lepton from W (semileptonic decay)
- Jet clustering to be 6 jet (Durham algorithm)
- Event shape cut (thrust, jet clustering)
- Find 4 b jets.
- Invariant mass cut for top and higgs candidates.

8 jet mode

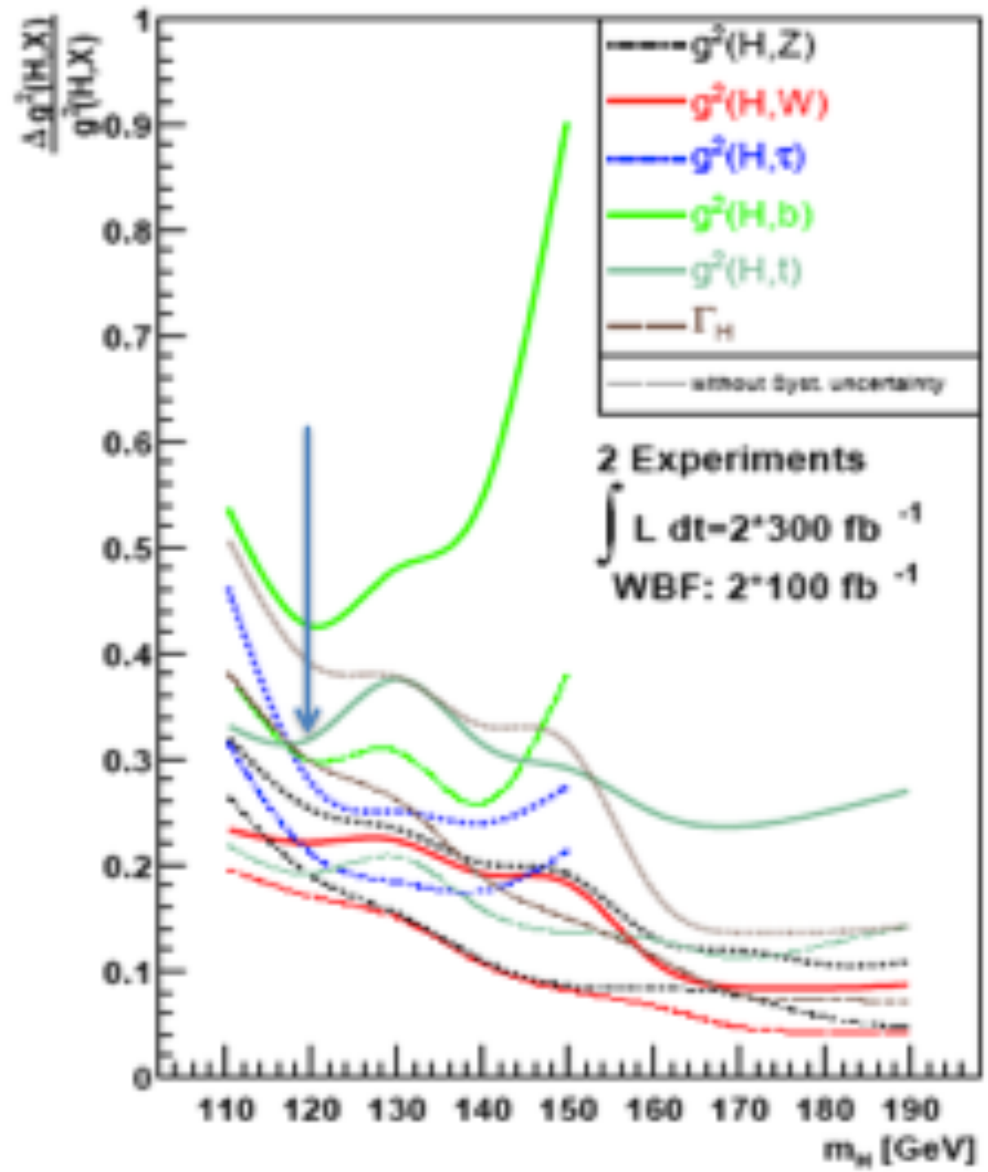
- Isolated lepton veto
- Jet clustering to be 8 jet (Durham algorithm)
- Event shape cut (thrust, jet clustering)
- Find 4 b jets.
- Invariant mass cut for top and higgs candidates.

situation at LHC

- at the LHC, direct measurement of the top Yukawa coupling (pp->ttH) is thought to be impossible due to too much background
- through indirect measurement involving gluon fusion with a top loop,



g_t measurement precision is estimated to be ~15% for M_H=120 GeV with 2 x 300 fb^{-1} data at E_{cm} = 14 TeV



data samples

process	xsec (fb)	generated events	equivalent luminosity (ab^{-1})
ttH	1.24	50,000	40.3
ttZ	4.04	50,000	12.4
ttg (g->bb)	1.93	50,000	25.9
tt	1440.	7,000,000	4.9
ttH	0.540	50,000	92.6
ttZ	1.324	50,000	37.8
ttg (g->bb)	0.859	50,000	58.2
tt	618	5,000,000	8.1

e-/e+ polarization = (-1.0, +1.0)

e-/e+ polarization = (+1.0, -1.0)